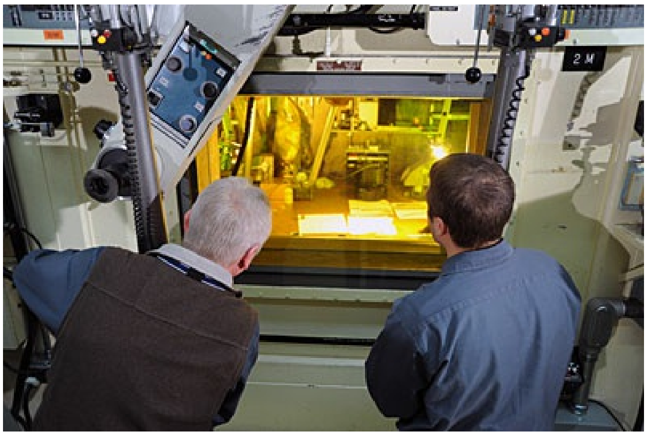


INL has developed a new way to analyze irradiated nuclear fuel, which can help engineers better understand how new fuel types stand up to prolonged irradiation so they can be safely used in commercial power reactors.

INL gains nuclear fuel insight with new examination approach

By Nicole Stricker, *INL Communications & Governmental Affairs*

Any materials scientists will tell you they can get a better understanding of how a substance behaves if they know what's happening at the microscopic scale. For example, we know that sunlight damages rubber and plastics because UV rays cause molecules to cross-link to each other, which ultimately reduces elasticity.

The precautions necessary to protect workers make irradiated fuel sample preparation extremely challenging for researchers.

Detailed microscopic insights are harder to come by for those studying how nuclear fuels and structural materials behave inside reactors. It's important for engineers to understand how new fuel types stand up to prolonged irradiation before these materials are used in commercial power reactors. But such understanding can be a challenge when it comes to handling and studying extremely radioactive materials.

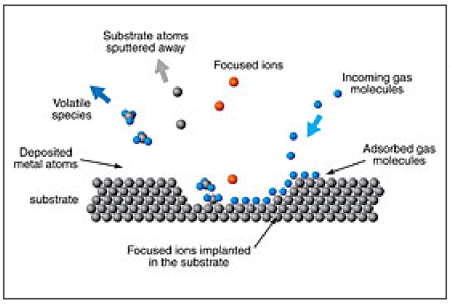
Substances irradiated inside a test reactor are too radioactive to safely work with using the same techniques that other materials scientists employ. Irradiated fuel must be handled at a distance using remote manipulators, which can hinder the precision required to prepare samples for state-of-the-art microscopic analysis.

Idaho National Laboratory researchers have now cleared that hurdle. They recently demonstrated a new sample preparation technique that makes it easier for researchers to examine irradiated fuel at the nanoscale. This accomplishment revealed material behavior that suggests increased stability of a new type of reactor fuel. Further study and improvement in nuclear fuel performance are now much more attainable, said Dennis Keiser, a researcher in INL's Nuclear Fuels and Materials Division.

"If you look at the literature, microstructure information on irradiated fuel is very limited," he said. "This new preparation technique will allow people with interest in different fuel types to potentially have access to new information about nuclear fuel behaviors at a very fine scale. It will also provide key information for computer models, which need data on a fine scale to make models that accurately represent fuels and materials behavior."

Handling brittle radioactive microscopic samples

New nuclear fuel designs have the potential to last longer and bolster safety margins, but first they need to be extensively tested to understand their behavior under a range of conditions. INL's Advanced Test Reactor has several isolated experimental chambers where new materials can be intensely irradiated under controlled conditions. Once a new fuel or material has been irradiated, researchers examine it to see how it performed. Cracks, bubbles or other irregularities warrant closer scrutiny.



Focused Ion Beam technology now enables INL researchers to examine nuclear fuel samples that are just a few atoms thick.

Anyone who's ever watched astronauts use the Space Shuttle Remote Manipulator to maneuver payloads can imagine how hard it would be to use such a device to perform a precise task such as, say, removing a splinter from a child's finger.

That was the challenge facing researchers who wanted to examine irradiated nuclear fuel samples under a transmission electron microscope, or TEM. The device can magnify up to 500,000 times, revealing features a few nanometers (1-millionth of a millimeter) across. But to do so, it requires extremely thin samples that have been precisely polished and milled — processes that can shatter delicate pieces of irradiated nuclear fuel, which must initially be prepared using manipulator arms extending inside radioactive "hot cells."

"You're dealing with this brittle material that wants to break apart," said Keiser. "The first question was, 'Could we cut this small sample and have it stay together?'"

After practicing on less radioactive materials and refining methods by trial and error, INL researchers perfected their approach for preparing irradiated fuel samples. First, they home in on microscopic areas of interest — specimens are on the order of 1/100th of a millimeter across. This approach makes the samples less radioactive and dangerous to deal with, eliminating the need for manipulators and hot cells.

Once INL researchers were able to obtain tiny, intact pieces from the fuel plate, they had to make the samples thin enough to analyze with a TEM. The new sample preparation technique — called "Focused Ion Beam In-Situ Lift-Out" — makes this possible. It mills the material with an ion beam to yield sections that are just tens of nanometers thick, which can reveal new features under a transmission electron microscope.

"Based on the literature, no one has ever done this on irradiated fuel," Keiser said. "And our colleagues around the world were skeptical that we would be successful."

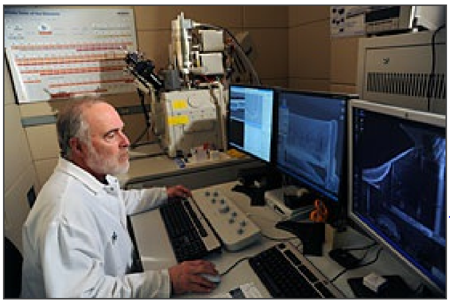
Did You Know?

The Center for Advanced Energy Studies (CAES) at INL contains another focused ion beam, a local electrode atom probe (LEAP) and other high-end equipment at its Microscopy and Characterization Suite (MaCS). CAES operates MaCS as a user facility so researchers from INL, academia, government agencies, private industry and other entities can use it to solve various technical problems.

Spotting signs of super-stable fuel

Researchers are still analyzing the data they're collecting from this approach, but initial findings are promising. For example, the fuel they examined contained an organized lattice of gas bubbles that suggests enhanced irradiation stability.

Inside nuclear fuel pellets or plates, the fission process generates microscopic gas bubbles. The fate and organization of these bubbles can affect how the fuel swells and whether it remains stable throughout the fuel's irradiation life cycle. Fuel stability can ultimately impact how long it can stay inside a reactor before its integrity becomes compromised. The TEM data showed that bubbles inside an experimental INL fuel design emerged in a highly organized lattice that could confer increased stability.



A Focused Ion Beam, shown, enables close examination of irradiated fuel using a transmission electron microscope.

"The requirement of nuclear fuel is that it maintains its dimensional stability; a lattice like that maintains very good stability during the fission process," Keiser said. "Part of the research is to understand what is the limit of the material before it breaks down — materials that don't exhibit this behavior can be less stable."

The research group published similar findings in a January 2010 issue of the Journal of Nuclear Materials, but its latest accomplishment demonstrates the validity of the new sample preparation technique. In other words, they've now demonstrated an easier way to produce similarly high-quality results.

"This work was a success due to the efforts of many individuals," Keiser said. "Without the significant contributions of people like Jim Madden, Brandon Miller, Jian Gan, Jim Cole, Jan-Fong Jue, Adam Robinson and other members of the Irradiated Materials Microstructural Characterization team at INL, this breakthrough work could have never happened."

The approach, INL researchers predict, could inspire a host of new discoveries related to nuclear fuel research, design and development.

"Once you get to this scale, it just opens the door to new information," Keiser said. "It's almost like going to space and seeing a new planet for the first time."

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